

Mid-Infrared Spectral Evolution of Amorphous Magnesium and Iron Silicate Smokes Due to Vacuum Annealing at $T \geq 1000\text{K}$. Susan L. Hallenbeck^{1,2}, Patricia Daukantas³ and Joseph A. Nuth¹, ¹Code 691, NASA-GSFC Greenbelt, MD 20771, USA, ²NAS/NRC Resident Research Associate, ³Astronomy Department, University of Maryland, College Park, MD 20740, USA.

Amorphous silicate particles are formed in the outflows surrounding oxygen rich stars and in the primitive solar nebula via condensation of vapors rich in Fe, Mg and SiO at temperatures in excess of 1000K. Grains that remain at such temperatures will be annealed to some degree: the infrared spectra of initially-amorphous silicate condensates should therefore evolve as a function of time and the temperature of their environment. We have carried out a series of vacuum annealing experiments in initially amorphous Fe-SiO_x and Mg-SiO_x smokes and have obtained several interesting results. First we find that Fe-SiO_x smokes anneal at a much slower rate than do comparable Mg-SiO_x smokes. As an example, at 1000K the infrared spectra of amorphous Mg-SiO_x smoke samples change on timescales of several days whereas to obtain similar changes on similar timescales in Fe-SiO_x smokes requires temperatures of ~1300K. Quantitative comparison of the annealing rates of Fe-SiO_x and Mg-SiO_x smokes are complicated by the fact that the infrared spectra of the annealed smokes differ significantly. The peak absorption for the Fe-SiO_x smoke occurs at 8.9 microns with a FWHM of 1.3 microns whereas the annealed Mg-SiO_x smoke has a dual maximum at 9.8 and 11.0 microns and a FWHM of 2.7 microns. Nevertheless, semi-quantitative estimates of the degree of spectral change observed vs. annealing time and temperature are easily sufficient to support the conclusion that Mg-SiO_x smokes anneal at a rate many orders of magnitude more rapidly than do Fe-SiO_x smokes.

A second conclusion of our initial experiments is that both the infrared spectrum and the rate of annealing of Mg-SiO_x smokes appears to be dependent on the initial concentration of magnesium in the smokes. Magnesium-rich smokes have a larger 11 micron absorption feature (compared to the 9.8 micron peak) than do magnesium-poor samples and they anneal more rapidly. Again, quantitative results are somewhat complicated by the fact that the smokes may un-

dergo some degree of magnesium loss (probably due to volatilization of metallic magnesium) during the initial stages of vacuum annealing. However, since experiments carried out at 1000K on "low-magnesium" smokes anneal on a timescale of 3-4 days whereas "high-magnesium" smokes evolve the same spectral features in ~12 hours we are reasonably confident that the rate does depend to some degree on magnesium concentration. Experiments are underway to quantitatively analyze this effect.

The spectral evolution of the magnesium silicate smokes proceeds in a very interesting manner. The spectra of the smokes initially evolves on a relatively rapid timescale until reaching a point at which it appears to stall. Further annealing has little effect for a timescale that is roughly comparable to twice the time needed for the initial sample to reach the "stall", after which the spectra again begin to slowly evolve. The positions of the spectral features observed in the "stalled" samples are virtually identical despite differences in the annealing temperature, the initial concentration of magnesium or the relative intensities of the features. Furthermore the "stalled" low-magnesium silicate spectrum provides an almost exact match to the infrared spectra of the silicate grains in Comets Mueller, Bradfield, Levy, Halley and Kohoutek, all of which have been observed to contain "olivine-rich" dust. Our experiments will provide a natural explanation for the similarity in the spectra of amorphous silicate dust from a variety of comets and stars, namely, the rapid evolution of initially amorphous silicates to the "stall" spectrum followed by the persistence of this signature for a reasonably long timescale in a cooling environment. In addition, because the 9.8 micron peak in annealing Mg-SiO_x smokes is established in roughly half the time required for the growth of the 11 micron feature, our experiments imply that most circumstellar and interstellar silicates are only half way to the stall spectrum.